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A COMPARISON OF THE CLIMATE OF THE EASTERN UNITED STATES DURING THE 1830'S WITH THE CURRENT NORMALS

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ABSTRACT

A comparison of climatic data for the eastern United States from the 1830's and 1840's with the currently valid climatic normals indicates a distinctly cooler and, in some areas, wetter climate in the first half of the last century. The recently appearing trend to cooler conditions noticed here and elsewhere could be indicative of a return to the climatic character of those earlier years.

1. INTRODUCTION

Except for the well-known climate amelioration of the last half of the 19th and first half of the 20th century, climatic changes of large scale are recognized largely by interpretation of a variety of nonmeteorological evidence. This evidence is generally related to a complex interplay of meteorological parameters with nonmeteorological factors and thus cannot be directly translated into standard climatic measures. Instrumental climatic records for the United States are nearly completely limited to the last 100 to 150 yr.; thus only this most recent change and possibly the end of the climatic episode immediately preceding it are amenable to climatic analysis based upon actual meteorological observations using instruments.

This penultimate climatic episode, called the "Neoboreal" by Baerreis and Bryson [3] and also frequently referred to as the "Little Ice Age" (Brooks [6]) apparently started during the middle of the 16th century at a time of glacial advances both in Europe and North America. It continued as a distinctly cooler, and, in some regions, wetter period well into the 19th century. Following it was a warming trend that between 1880 and 1940 to 1950 became quite pronounced in very many regions of the Northern Hemisphere (Willett [22], Mitchell [15], Conover [9]). During the last two decades there appears to be some evidence that this warming trend of the last 100 yr. has changed over recently to a distinct new deterioration of the climate, leading to conditions that in the 1960's appear to approach those which were generally found around the turn of the century or even earlier, i.e. a return to the climatic character of the 19th century (Lamb [12]).

Standard climatological technique for investigation of such climatic changes in meteorological records is the careful analysis of long and, if at all possible, uninterrupted records of a few carefully selected stations, taking into account all kinds of possible effects which might have influenced the basic trend of the data, e.g. the changing exposure of instruments, changes in instrumentation and observational techniques, effect of human activity such as growth of a city, etc. Clearly, this complicates matters extremely, and effectively reduces the availability of suitable records to usually only a very few stations in any one part of the world. It also has a very undesirable effect on our ability to establish really "large-scale" changes; it is very unlikely that the essential features of a climatic change should happen to occur just at those locations where we have a long and reliable record. Most of the really long records in the United States come from areas of population concentration in the early 19th century; and while European records are reasonably well distributed over at least the Western European area, our centers of population were located near the coast of the Atlantic from Boston to Florida to Louisiana, with very few data and practically no long uninterrupted records available inland. West of the Mississippi, no reliable records can be found which allow a detailed study of one particular station.

It therefore appears rather hopeless to approach the problem of establishing the climatic change during the last 100 yr. in the United States in the conventional manner. On the other hand, there exists a large amount of observational data sources, at least in the eastern half of the United States, that individually are extremely inhomogeneous but which, as a statistical collective, may be utilized to achieve a gross picture of the climatic behavior in this last part of the Neo-boreal, the time period preceding the recent "warming of the Northern Hemisphere." Judicious use of statistics and the recognition of a large random element in the data—which however can be suppressed by considering large data samples—actually have provided some rather interesting results that will be reported in this paper.

2. THE VALUE OF THE EARLY OBSERVATIONAL RECORDS

It has been argued that meteorological measurements taken in the early years of the last century must be distinctly inferior to our current day measurements, due to faulty thermometers, poor regard for "proper" exposure, and general lack of understanding of the essential requirements for good observations (e.g. Willett [22]). This may well be true in a number of individual cases; however, one should remember that, in those days, the making of meteorological observations was largely in the hands of—for their times—highly educated people who performed these observations with intense interest as a sort of intellectual hobby probably very similar to the amateur astronomer of today who is certainly a most valued participant in astronomical research of our times. In the compilation of records (Schott [16]), which formed one of the bases for this study, there are published for the state of New York, for example, monthly temperature averages for a total of 212 stations. Sixty-three of these are denoted as "Academy," "College," or such; and another 14 came from military installations where, at those times, the surgeon was usually responsible for the meteorological observations [13], [14]. The latter, by the way, had been issued extremely carefully composed and meteorologically sound instructions on how to make the observations—which was true in fact for all observations done by the military at those times. It is thus likely that the data from such sources are quite reliable—excepting perhaps the effect of exposure which might have introduced systematic errors in the individual records; even these, however, should not be too critical especially if one combines a reasonably large number of stations.

It would be advantageous to have some corroborative evidence at least from one or two stations to estimate the reliability of the early records on an objective basis. Fortunately, such evidence can be obtained and will be presented below. Assuming then that a use of these rather inhomogeneous records is permissible and that results, with proper caution, can indicate valid climatological conclusions, it appears possible to compare the essential features of the climate of the middle of the last century with those of our modern times and point out, in this way, the overall character of the last part of the climatic episode preceding our recent era, the only one extending into the instrumented era.

3. COMPARISON OF TEMPERATURE AND PREVAILING WIND DATA

In conjuction with other investigations into the prehistoric and early historic records of the Wisconsin area, the early meteorological data taken by Army Surgeons at several military posts in this region were investigated in some detail. As usual with such records, we have available data for only a limited number of years (in part incomplete). More recent observations, under the auspices of first the U.S. Army Signal Corps and later the U.S. Weather Bureau, were, in nearly all cases, taken at different locations and thus, strictly speaking, cannot be "exactly compared" to the earlier data. Nevertheless, in spite of these shortcomings, it was felt that the information content of those early observations is still extremely valuable, if for no other reason than that there are no other data available: Any results would help to enlarge our knowledge of this not too distant past.

As an example, the records from Ft. Winnebago [2] will be detailed. This Fort was an Army post established on the Wisconsin River near Portage, Wisconsin, on the overland route from the Great Lakes toward the West. Meteorological observations were begun in 1828 and, with some interruptions, were continued through 1845; the temperature records contain a total of 15 yr., 3 mo.; and similar record lengths exist for precipitation and wind data. In the data collections a detailed account of meteorological records exists. In addition to daily weather records, copious notes and remarks on the state and calibration of instruments, average temperature and precipitation values for individual months are compiled. Thus, it was possible to derive a set of average monthly temperatures including only those years that were complete; this reduced the data somewhat, from the 15 yr., 3 mo. above to 13 yr. (1829–32, 1835–43) with a very minor change in the annual course of averages which in only one case changed the monthly average by about 1°F. If one now compares these "normals" for the 1830's (records from 1829–1843) to the modern normals for the currently existing station at Portage, Wisconsin, a cooperative U.S.W.B. station, one finds that nearly all months are distinctly warmer now than they were in the 1830's with the largest change of between 4 and 6°F. in late summer and early fall. (See table 1.)

The daily (and consequently the monthly) average temperatures in the old records were derived by using

TABLE 1.—*Mean monthly temperatures Portage/Ft. Winnebago (Wis.) (Units °F.)*

Month	(a)	(b)	(c)	(d)	(e)	(f)
Jan	20.2	20.9	19.5	18.6	19.2	+1.7
Feb	22.4	21.9	18.5	16.6	18.1	+3.8
Mar.	32.2	32.7	32.6	31.6	33.8	−1.1
Apr	47.6	47.5	47.2	46.0	46.1	+1.4
May	59.6	59.6	56.7	56.6	56.9	+2.7
June	69.2	69.5	65.6	65.8	65.9	+3.6
July	73.9	74.6	71.0	70.8	70.9	+3.7
Aug	71.8	72.4	67.3	67.2	67.3	+5.1
Sept	63.5	64.3	57.8	57.6	57.4	+6.9
Oct	52.4	52.6	49.7	48.2	48.1	+4.5
Nov	36.8	37.3	32.1	31.6	32.3	+5.0
Dec	24.4	24.5	21.3	21.3	20.9	+3.6

(a): Portage, Wis., 30 yr.—normals 1931–1960.
(b): Portage, Wis., 18 yr.—averages 1931–1948.
(c): Ft. Winnebago, average of all available data regardless of missing values (1829–1845).
(d): Ft. Winnebago, average, for complete data only, of years 1829–32, 1835–43.
(e): Ft. Winnebago, average for record 1829–1842, as used for wind correlation.
(f): Column (b) minus column (e).

Source: [19] for (a) and (b) and source [2] for (c), (d), and (e).

the readings at either 7 a.m. or sunrise, 2 p.m. and 9 p.m. Modern climatic normals, however, are based upon averages derived from daily maxima and minima, and this change in procedure of deriving daily and monthly mean values can have a certain systematic effect on the resulting differences. However, some studies brought to my attention by Dr. J. M. Mitchell indicate that they cannot possibly explain the rather drastic changes shown in our results. Thus we have both an overall change plus an annual variation of the differences between the early and current records; even if one wished to ascribe the overall change to a systematic error in the old records, it still remains to explain the annual variation. It really does not matter what kind of average one uses—the one over "all records" or the theoretically more proper one excluding the years in which data were missing; one should keep in mind that we are looking here for effects of the order of several degrees while the "noise" in the data can be estimated to be of the order of a degree or less. There appears to be no question that the monthly averages from Ft. Winnebago in the 1830's were distinctly lower than our mormals now; in fact if one uses only the years 1931–48 (before the onset of the new cooling trend in the 1950's) the deviations are even larger.

The major question thus is whether the old data have a reasonable accuracy, i.e. whether the above differences are really climatically important—or whether they only indicate systematically faulty observations.

Fortunately there is a possiblity of testing this significance to a good degree. In the above mentioned data collections, there exist also daily records of the prevailing wind direction, and these records can be compared with similar data we have available from modern days. (These modern data were obtained, from the original observational records of the observers, through the courtesy of the ESSA State Climatologist for Wisconsin, Mr. H. Rosendal.) Unfortunately, a change in reporting format terminated the recording of this element in 1949; however, one can obtain frequencies of prevailing wind direction for 1931/48. In the 1930's the definition of "prevailing wind" was still the same as it was in the 1830's—no instruments are involved and only distinctly different exposure could introduce serious systematic errors. Table 2 contains a brief compilation of these wind data, compressed into the most useful form, namely listing the percentage frequency of "generally northerly" winds (those recorded as (NW, N, NE, and E)) for the two time periods: Ft. Winnebago 1829–1842, Portage 1931–1948, by mean months and also listing the lowest and highest number of days in this sector in any individual month of record in these two periods. Clearly apparent is the distinctly larger percentage of days with N-winds in the older records, which on the average reaches (especially in summer and fall) amounts close to or even beyond the factor of two. In fact, in July and August of the 1830's it was about equally likely to have winds from the north as from the south; in contrast to this, in the 1930's the likelihood for N-winds is only one in four or less. Since one knows that in general terms N-wind will bring cooler air into the region, these two results—colder temperatures and more northerly winds—agree very well indeed.

TABLE 2.—*Frequency of prevailing wind from NW, N, NE, and E*

Month	Ft. Winnebago				Portage			
	No. of days	%	Min. no. of days	Max. no. of days	No. of days	%	Min. no. of days	Max. no. of days
Jan	17.4	56.1	7	26	10.6	34.1	5	19
Feb	15.4	54.5	4	25	10.1	35.8	6	17
Mar	16.0	51.6	3	26	12.3	39.7	7	21
Apr	16.8	56.0	5	26	11.8	39.3	8	20
May	17.2	55.5	10	26	10.3	33.2	6	15
June	16.8	56.0	5	27	7.8	26.0	3	14
July	14.3	46.1	6	24	6.9	22.3	2	13
Aug	15.8	51.0	4	23	7.7	24.8	2	14
Sept	14.0	46.7	6	24	8.0	26.7	3	11
Oct	15.7	50.6	7	26	7.8	25.2	3	13
Nov	19.5	65.0	11	26	8.9	29.7	6	13
Dec	17.3	55.8	4	27	10.9	35.2	7	18

Ft. Winnebago record 1829–1842.
Portage record 1931–1948.

However, one can go even one step further. Using the simultaneous temperature deviations ΔT (from the normal of the particular period) and the observed north-wind frequencies (again in deviation ΔN from the proper normal for the period), one can calculate the correlation coefficient r between ΔT and ΔN for the individual months. These correlations all are negative, as expected, ranging from about -0.2 to -0.7 depending on the individual data samples, i.e. months. Using these correlations one can also obtain the regression equation for ΔT as a function of ΔN:

$$\Delta T = c\Delta N$$

with the regression constant c being specified by

$$c = r\,\frac{\sigma(\Delta T)}{\sigma(\Delta N)}$$

$\sigma(\Delta T)$ and $\sigma(\Delta N)$ being the standard deviations of the ΔT and ΔN values.

If one now uses the change of mean number of days with N-winds between the 1830's and 1930's and, with the help of the appropriate regression equation, calculates the expected change in temperature, one can compare this calculated change (which is independent of systematic effects since each $\Delta T/\Delta N$ pair was obtained as deviation from its own period average) with the actually observed change in T.

The calculated changes for the various months range from $+1.0$°F. to 5.3°F., with an average change for the annual mean of *+3.0°F.* (i.e., the 1930's should be warmer by 3°F.). The actually observed deviations (col. (f) of table 1) range from -1.1°F. to $+6.9$°F., with an annual average of *+3.4°F.* This close agreement between the change "predicted" on the basis of wind frequency and the change observed by means of thermometers is rather remarkable, in fact the small difference of 0.4°F. is well within the RMSE of the individual differences (± 0.7°F.) and certainly not significant in a statistical sense. We can thus conclude that, in fact, the temperature differences which exist according to the observations in the 1830's as compared to the 1930's appear to be real and thus may well indicate a true climatic change.

It should be mentioned that the above test can be carried out for a number of stations. It was also performed with the data at Prairie du Chien, corresponding to the old Ft. Crawford data. Exposure of this location is rather different—both old and modern stations were located in the river plain of the Mississippi with a distinct predominance of either NW or SE winds. Nevertheless, the same results were obtained, i.e. more northerly winds in the 1830's together with lower temperatures and, using the regression technique, the temperature change could be verified from the change in wind direction frequencies. Essentially, these results strengthen the previously expressed view that temperature observations in the early periods appear to be reasonably reliable and not too much distorted by systematic errors.

4. DATA STATISTICS FOR THE 1830'S AND PROCEDURES FOR DERIVING DIFFERENCES AGAINST CURRENT CLIMATIC NORMALS

On the basis of these findings, a broader approach to the overall problem of the climatic changes over the eastern United States was attempted. From the above mentioned reference and a similar publication of the Smithsonian Institution on precipitation (Schott [17]), we extracted all data that contained records starting earlier than 1840. The data available in these two collections consist of average monthly values for temperature and precipitation amount, averaged over the length of record available at that particular station. Frequently, the records were not complete; however, the listings give both the total period covered (i.e. beginning and ending month/year) and the total available record length in number of years and months. The typical entry would be, for example, for Ft. Winnebago: starts Jan. 1829, ends Aug. 1845, extent 15 yr., 3 mo. In addition, the observing hours are specified if known and finally the source from which these data were obtained—frequently, a manuscript in some collection.

In order to specify more fully the kind of records used and their meaning in terms of "average," it may be well to scrutinize statistically the record length and time span contained in our sources. Temperature and precipitation records must be considered separately since they originate from different sources and show a somewhat different behavior.

Temperature records used in this investigation numbered 221 in all across the eastern United States; the median length of records was 14–15 yr. with 50 percent of the records having a length of between 5 and 26 yr., the median starting date was found to be 1828, the median closing date 1852 with again 50 percent of the records beginning between 1823 and 1831 and ending between 1841 and 1867. In fact, if one would define an "Average Record" then it would center on 1840, run for the 24 yr. between 1828 and 1852 and contain, within that time span, 15 yr. of actual observations. One thus can state that any results may be ascribed to an average climatic behavior in the 1830's and 1840's just about 100 yr. prior to our currently valid climatic normals (1931–1960).

The precipitation records were not so numerous; only 115 records could be used. Median length of record was about 16 yr. with 50 percent of all records between 7 and 27 yr. of length. Median starting date was 1831, ending date 1859 and the "Average Record" would be centered on 1845. While these two "Average Records" do not exactly correspond to each other, they are closely spaced and essentially both describe the climatic conditions in the 1830's through 1840's and into the 1850's.

One of the major questions, apart from the one discussed above, is the problem of comparing these data with the modern climatic pattern as given in the Climatic Normals. Two different methods were attempted and, since the results in most cases complemented each other, the arithmetic mean of the two comparisons was used as the final answer. Firstly, every old record was compared to the best possible modern station in its vicinity (or the modern record of the same station if available) taking into account the possible topographic difference by sometimes comparing a station to the average of two modern stations if the old one was located somewhere between the two modern ones. The individual monthly averages (given in the two data collections), formed over the length of record as specified in these sources then were either directly compared to the 1931/60 normals (for temperature) resulting in a monthly value of ΔT_1 or were compared as deviation in percent of the current normal (for precipitation) resulting in monthly values ΔR_1 percent.

Secondly, the same old records were similarly compared to the "Normals for Climatological Divisions" (U.S. Weather Bureau [20]). This comparison, carried out as above, has the advantage of comparing the old record with the larger-scale climatic features of the general region; one thus does not compound errors which are due to topographic effects in the old records by additional ones in a particular new station, both effects possibly becoming additive. The resulting ΔT_2 and ΔR_2 in most cases differed only in degree and rarely in kind from those obtained as ΔT_1 and ΔR_1 above. Finally, the simple arithmetic means, of these deviations were taken:

$$\Delta T = \frac{\Delta T_1 + \Delta T_2}{2} \text{ and } R = \frac{\Delta R_1 + \Delta R_2}{2}.$$

This preliminary result was plotted on maps to ascertain that the data made sense at all—which in fact they did. It also, however, was quite obvious that in those areas where a number of stations were reasonably close together, one could see systematic differences between stations. These differences (especially if they appear in both the ΔT_1 and ΔT_2 (or ΔR_1 and ΔR_2) in similar manner) obviously indicate systematic effects in the old data which on a single

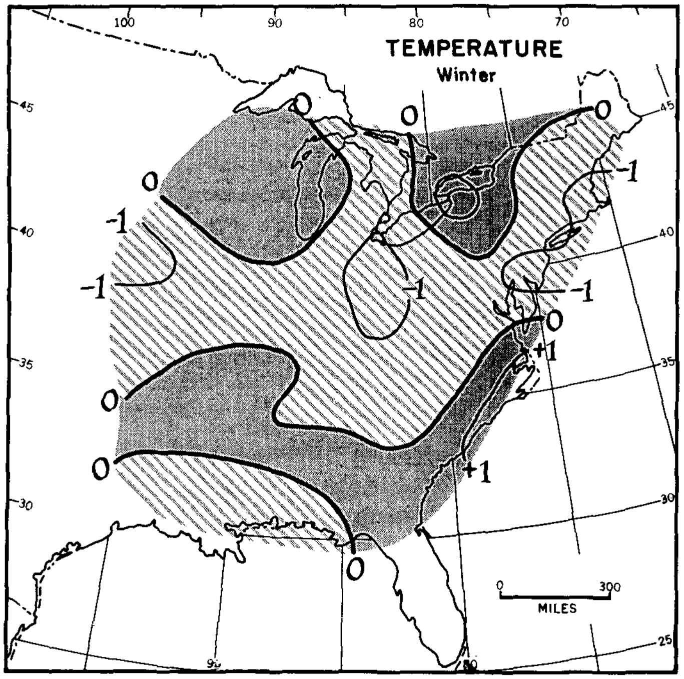

FIGURE 1.—Temperature deviations (°F.) of the data in the 1830's from climatic normals 1931–1960. Winter (Jan.–Mar.).

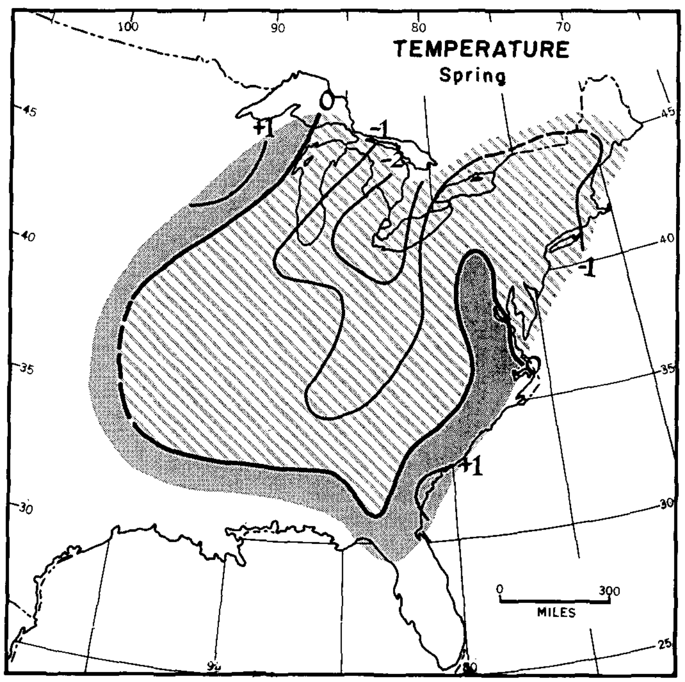

FIGURE 2.—Same as figure 1. Spring (Apr.–June).

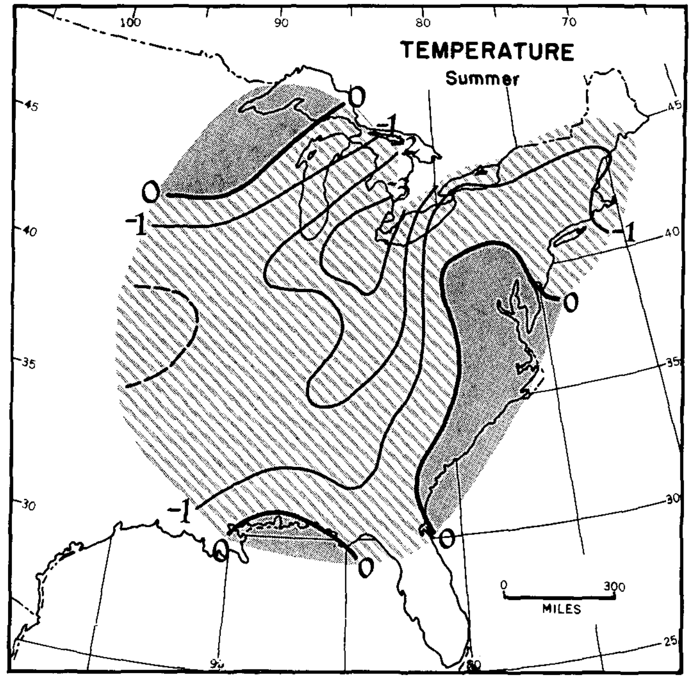

FIGURE 3.—Same as figure 1. Summer (July–Aug.).

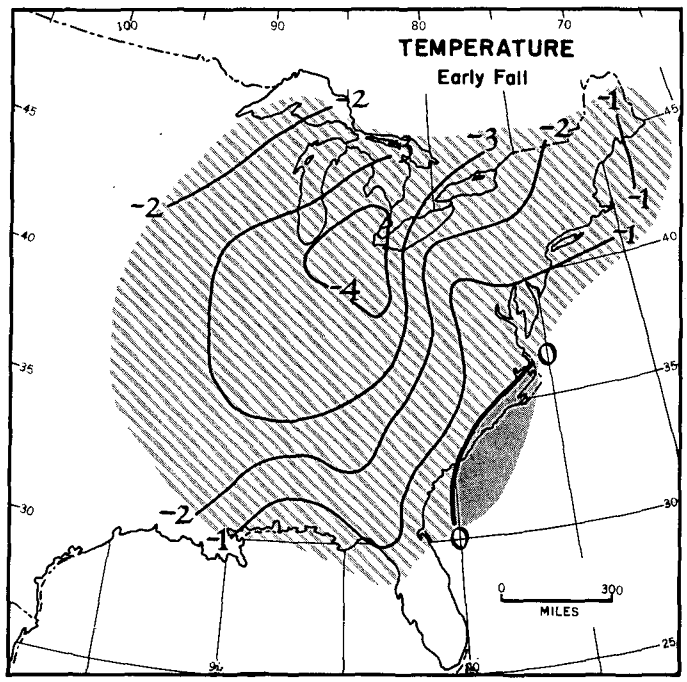

FIGURE 4.—Same as figure 1. Early fall (Sept.–Oct.).

station basis cannot be resolved easily without digging into the original data themselves. But one can achieve a more meaningful result nevertheless by now combining a number of such regional records into an "area record." This was done, by forming for each average month a weighted average of the ΔT and ΔR of the stations within a region, with the weights assigned proportional to $\sqrt{N}$, N being the number of actual months of observations used at that particular station for the published averages. Regions were chosen to a) include at least two and if possible, more stations, and b) to take into account wherever possible at least the gross climatic divisions. For example, in the western part of the eastern United States (i.e. between Ohio and the Mississippi) regions are large and have rather few stations; farther east, regions are smaller and more stations are included.

For a total of 29 such regions in temperature and 26 regions in precipitation, mean monthly ΔT- and ΔR-values were obtained; most of the regions for the two elements are essentially the same. The missing three regions in

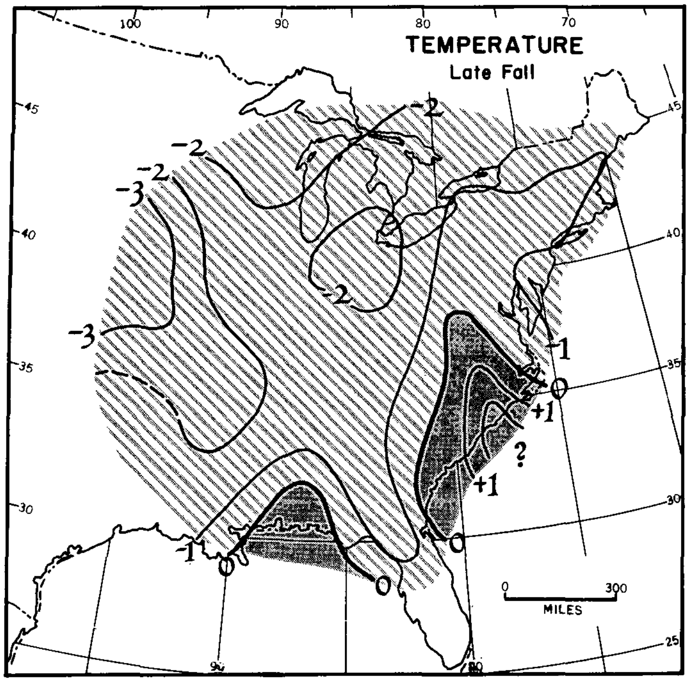

FIGURE 5.—Same as figure 1. Late fall (Nov.–Dec.).

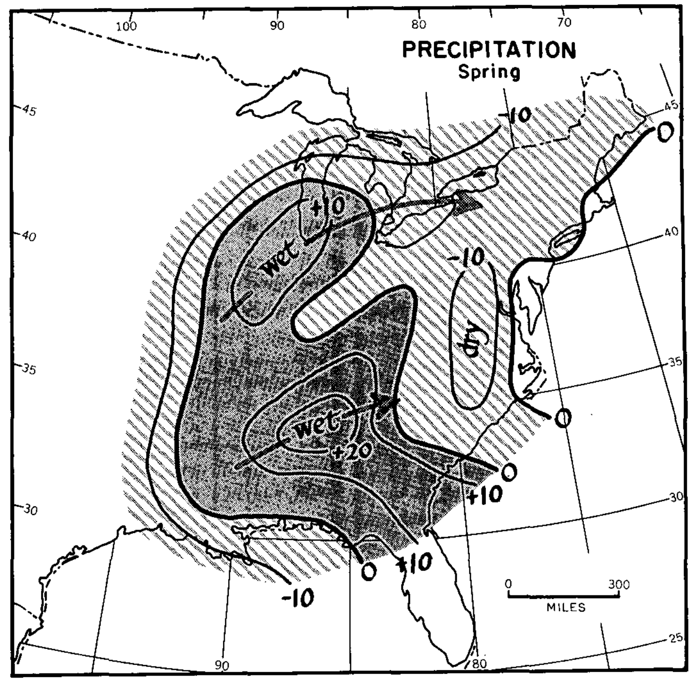

FIGURE 7.—Same as figure 6. Spring.

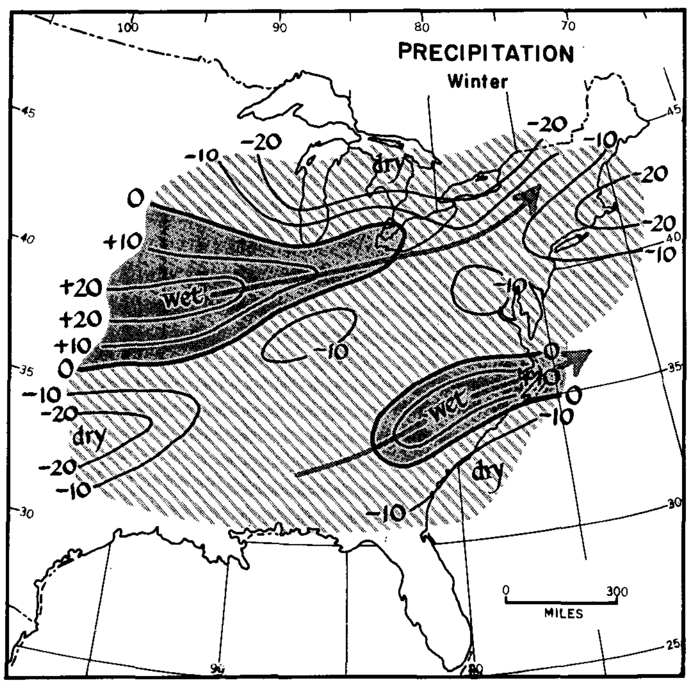

FIGURE 6.—Precipitation departures of the data in the 1830's and 1840's from climatic normals 1931–1960 (in percent of normal amount). Winter.

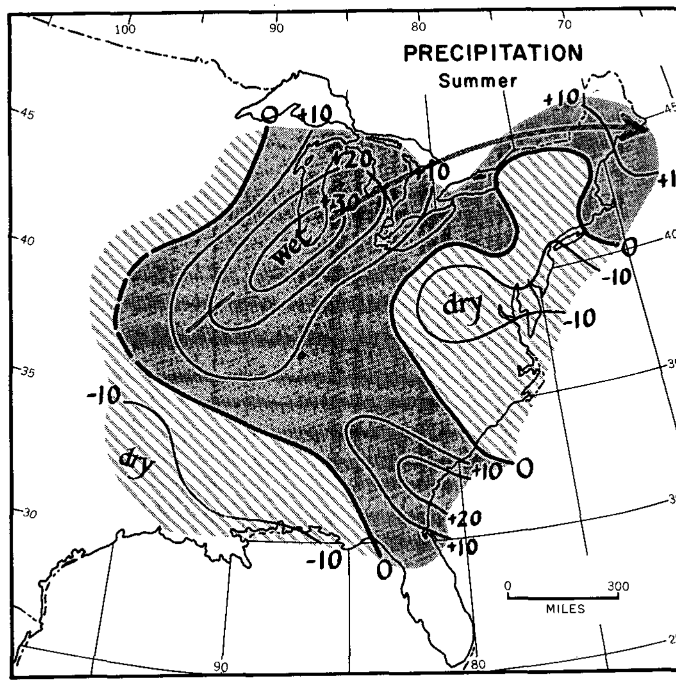

FIGURE 8.—Same as figure 6. Summer.

ΔR are those where no R-records were available but some ΔT-data could be obtained. On the basis of the annual behavior of these regional Δ-values, it was decided to combine the deviations into seasonal averages, defining for this particular purpose five seasons: winter (January–March), spring (April–June), summer (July–August), early fall (September–October), and late fall (November–December). Maps for the temperature and precipitation deviations in these five seasons are shown in figures 1–5 and 6–10 respectively. Figure 11, giving the average annual temperature change map, contains also the actual ΔT values, entered in the appropriate place indicating the region to which they apply.

5. DISCUSSION OF RESULTS

The above maps rather clearly indicate a substantial and coherent pattern of change both in the annual and the seasonal averages of temperature and precipitation over a time interval of about 100 yr. It is interesting to note the largest changes, in temperature especially, occur

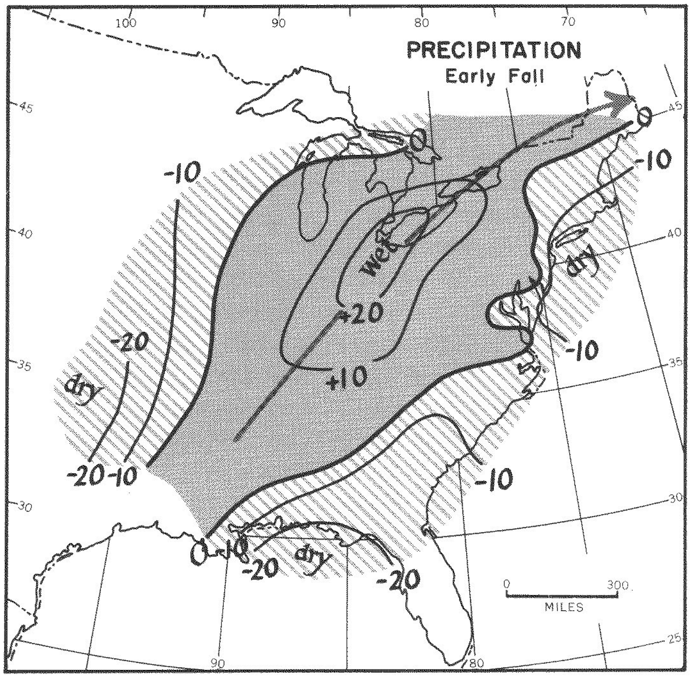

FIGURE 9.—Same as figure 6. Early fall.

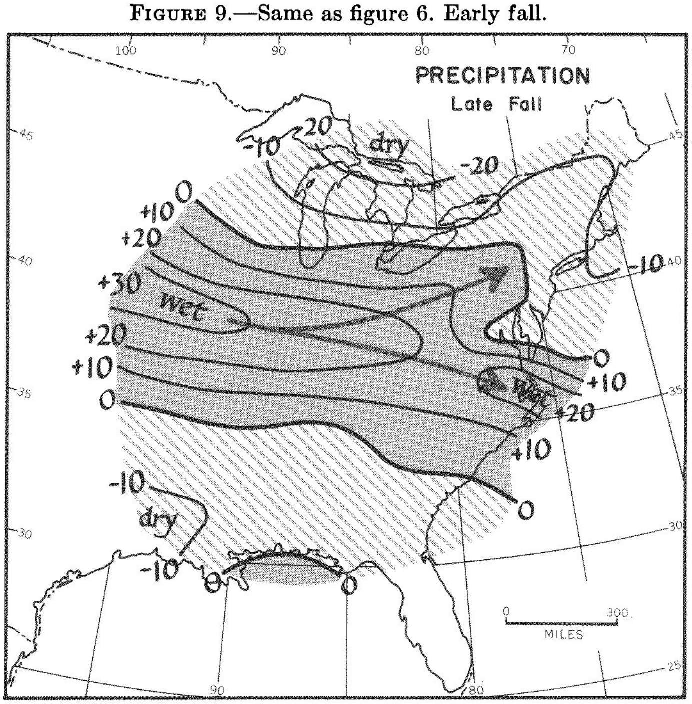

FIGURE 10.—Same as figure 6. Late fall.

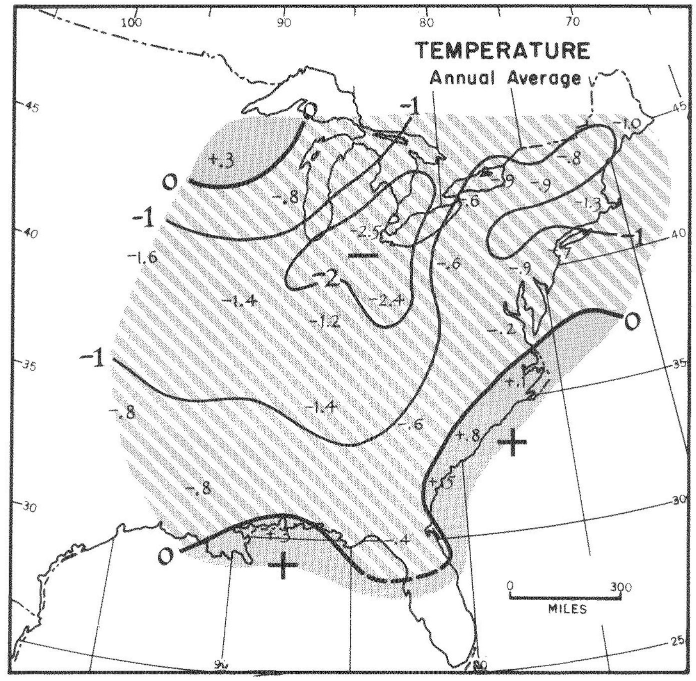

FIGURE 11.—Average annual deviation (°F.) from climatic normals 1931–1960. Position of numbers on map indicate value for area surrounding this value.

well inland while the coastal regions are much less affected. The meaning of this change with respect to its geographical pattern, its size, and its variation within the seasons will be discussed below.

On the map depicting the change in the *annual* temperature averages (fig. 11), core values in the region of Indiana, Ohio, and Kentucky amount to approximately 2°F. How significant are such differences from two sets of data about 100 yr. apart? Assuming that the variance of annual temperature averages (say, for a climatic region) has not changed significantly, one can easily test the significance of this difference by means of the "Student t-test." From the current normals (30 yr.) of annual average temperatures for a climatic division (central Indiana), a standard deviation of 1.33°F. was obtained; then the total standard error for the combined series consisting of the 15 yr. of early data and the 30 yr. of data in the modern normals is 1.36°F. The t-value from

$$t=\frac{M_1-M_2}{\sigma\sqrt{\frac{1}{N_1}+\frac{1}{N_2}}}$$

equals about 4.7 with 43 degrees of freedom (N_1+N_2-2). The expected t-value at the 99.5-percent level is 2.6; consequently the actual value exceeds this level considerably so that the assumption that the two series with means M_1 and M_2 come from the same basic population must be rejected well above the 99.5-percent significance level; in fact this high t-value leaves practically no doubt that two different populations must exist.

A similar calculation was performed for the September/October data where the maximum values in the core reach 4°F. Again testing as above we find $t\sim6.4$, another highly significant result which also indicates that even much smaller changes should still be significant. For example, $t=1.68$ for the 95-percent level; consequently, even a difference of 0.7°F. in the annual and 1.0°F. in the seasonal means still would be significant at the 95-percent level. Thus the gross patterns certainly must be considered of climatological significance and the values themselves as an indication of a highly important climatic change, namely a distinct warming of the climate in the last 100 yr.

It is noteworthy that the pattern (with a core in the eastern Midwest) is rather consistent throughout the year; practically all months (with the possible exception of March) were somewhat cooler in the 1830's than they were in the time around 1930 and 1940. The warming appears to have taken place essentially to the west of the Appalachians with a northeastward extension toward New England. Along the Gulf and Atlantic coast up to Virginia the changes were either nonexistent or only of minor importance, in fact the Appalachian Mountains seem to be a distinct barrier to this pattern as if the cold air which causes this negative departure from the current normals was stopped by the mountains from further progress toward the southeast. Most of the earlier investigations of recent climatic changes, however, have been attempted using the long and thoroughly investigated records from stations generally located near or at the East Coast (Church [8], Conover [9], Mitchell [15]). It now becomes apparent that very little change should have occurred at such stations as Charleston, S.C., New Orleans, La., etc. Only farther north, this warming trend from the 19th to the 20th century is somewhat more pronounced, in good agreement with the result obtained from stations such as Boston, Blue Hill, Providence, and New York (Church [8], Willett [22]).

A somewhat unexpected result was the behavior of this warming trend in the different seasons. The largest change appears to have occurred in early fall (September/October) with values in the core area of at least 4°F. Synoptically, such a change can be explained most easily by the more frequent and probably also more persistent influx of polar air into the Midwest, leading to the prolonged buildup of cold anticyclones in the early fall season. This reason rather than less frequent warm air advection also is indicated by the blocking of this pattern by the mountains, which will effectively prevent the cold air from reaching (on the average) the coastal plains and the Atlantic coast. It also explains the steady decrease of the departures toward the Gulf. Finally, this explanation also is consistent with the fact that, in the northern part of our maps, along the Canadian border, not much change is noted. In these regions even today we have frequent and extensive cold air advection going on.

The precipitation changes in this season are of further interest. Just overlying the core area of maximum temperature departure (in early fall) is an area of somewhat higher precipitation amount in the early period. This also fits rather well with the assumption above, i.e., the more frequent outbreaks of cold air from Canada. The still quite strong influx of moist Gulf air, coupled with early polar cold fronts will, in that season, result in more frequent and more intense shower activity and thus an increase of total precipitation. The drier region both in the South and along the East Coast is interesting. From a survey of frequency of hurricanes in the last 100 yr. it was found that fewer penetrated into the Gulf in the middle of the last century while (some) more were found in the Atlantic regions (Kahn [11]).

In late fall, the negative departures in the whole core area decrease distinctly (in the temperature maps) and the band of above-normal precipitation now appears to be oriented approximately west-east with its axis across southern Illinois and Kentucky. The cold air outbreaks apparently extended farther south than now so that at their southern edge there was again increased shower activity. The streakiness apparent in the precipitation maps can most easily be understood in terms of a slightly more southerly location of the average cyclone paths in the 1830's. Such a shift would also shift the areas of maximum rainfall resulting in slightly higher amounts near the earlier cyclone paths and lesser amounts to the north where the maxima now occur. The arrows in figures 6–10 are intended to indicate in a very general way, the probable preferred cyclone tracks in the 1830's as deduced from these rainfall patterns. All in all, the two sets of maps confirm each other in general terms quite well, in essence indicating a substantial change in the climatic behavior in the eastern Midwest.

6. CORROBORATIVE EVIDENCE

The above result of a rather definite warming trend from the 1830's to the 1930's is based upon a statistical analysis of data obtained from instrument observations. There are, also, some additional pieces of evidence which confirm these findings or at least can be understood most easily if our above results are accepted as valid. Some of these will be presented here.

The rainfall records of the 1830's in Wisconsin show the typical summer precipitation maximum with a distinct peak in July and lesser amounts in the adjacent months. In a compilation of data published in 1912 [21], a quite similar pattern is apparent, the maximum now occurring in June with July closely approaching the same value. August is decidedly drier than each of the 3 months May through July. In the currently valid normals, based on data between 1931–1960, however, we find the major peak definitely in June, with a secondary maximum in August while July is now a distinctly drier month (except in south-central and southeastern Wisconsin where July and August are about equal). This change can be understood by comparing this modern pattern with the seasonal shift in the location of the Polar front; the two rainy peaks correspond well to the passage of this front through Wisconsin northward (in June) and again southward (in August) while it is situated, in July, well to the north at or north of Lake Superior [71]. Apparently, the cooler summers in the last century are related to a more southerly location of the Polar front which in July stalled across Wisconsin rather than reached north to Lake Superior. This also is indicated by the much higher frequency of northerly winds in the early records, giving about equal probability of N and S winds, as was discussed earlier. Together with this more southerly position of the Polar front in the 1830's we can assume also a displacement of the position of the major storm tracks, resulting in a southward dislocation of the bands of precipitation, as discussed before.

Another piece of evidence can be obtained from data which are rather independent of actual temperature measurements. In one of the earliest texts on the climate of the United States, Blodget [5] has collected a wealth of information on the climatic behavior of the United States for a time period essentially comprising the first half of the 19th century. Among this, he has listed, for a number of locations, the mean date of the last spring and first fall frost, based upon the effect of this event upon the vegetation. Similar records are also available for our modern days [18]; while the definition may have been more specific by referring to actual temperature measurements, the actual date of the last "killing frost" obviously should be rather similar if the climate were the same as in the 1830's. Actually, in every case the date of the last spring frost was later in the last century and the date of the first fall frost earlier. (See table 3.) Especially interesting is the fact that the data of Cincinnati also show the largest time difference (consistent in both spring and fall)—exactly as one would expect it on the basis of our earlier results. At Natchez, a much less pronounced change in dates occurs, again in agreement with our earlier results that indicated a much less pronounced change in mean temperatures near the coasts.

TABLE 3.—*Dates of last spring and first fall frost*

Station	Year	Spring	Fall
Near Cincinnati, Ohio	1814/48	May 6	Oct. 3
	1899/1938	Apr. 12	Oct. 25
St. Louis, Mo	1824–53	Apr. 6	Oct. 26
	1899/1938	Apr. 2	Oct. 29
Muscatine, Iowa	1850/56	May 6	Sept. 24
	1899/1938	Apr. 25	Oct. 10
Natchez, Miss	1825/50	Mar. 22	Nov. 9
	1899/1938	Mar. 13	Nov. 13

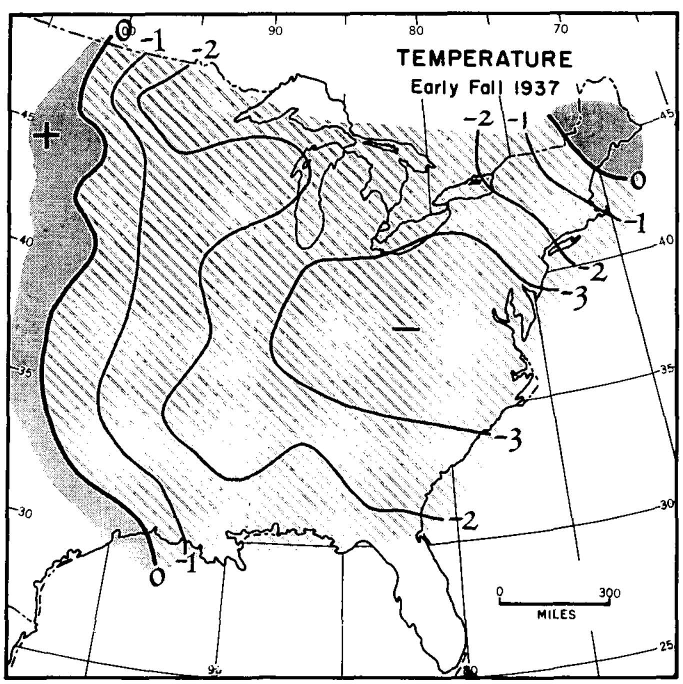

FIGURE 12.—Early fall temperature departures from normal, September/October 1937.

286-236 O—68——2

One last piece of evidence, again related to a gradual warming trend in the last 100 yr., is based on an investigation of the dates on which Lake Mendota at Madison, Wis., either froze over in fall or opened in spring. Bhattacharyya and Klotz [4] have studied the record of this Lake with great care, applying modern statistical techniques, and find that a definite trend exists in the sense of a delay in the freezing and an advance in the opening date of approximately 10 days each over 110 yr. The results were shown to be definitely significant in the statistical sense. From a different investigation [10] we know that Lake Mendota is a good integrating mechanism for the temperature behavior of the last 4 weeks before freezing. The trend found above thus indicates that temperatures in the early years of the record should have been somewhat lower, again in line with our other results.

7. CONCLUSIONS

It is intriguing to consider what kind of months would be required to make up such a pattern of large mean deviations from our current normals. The normals for 1931–1960 encompass that period which over nearly the whole Northern Hemisphere was the warmest in the last 100 to 200 yr.; nearly all stations in both the United States and Europe show higher values in their normals than any earlier 30-yr. periods. It may well be that one has to consider not the 1830's and 1840's as the abnormal decades, but may have to assume that the recent years constitute a temporary departure from the more "normal" behavior at those times. How "abnormal" (in this sense) these modern years are, can be seen from the fact that it was not possible to find a single year in the 30 yr., 1931–1960, which exceeded the "mean" deviations of our maps. Only 2 years (1937 and 1957) showed a somewhat similar

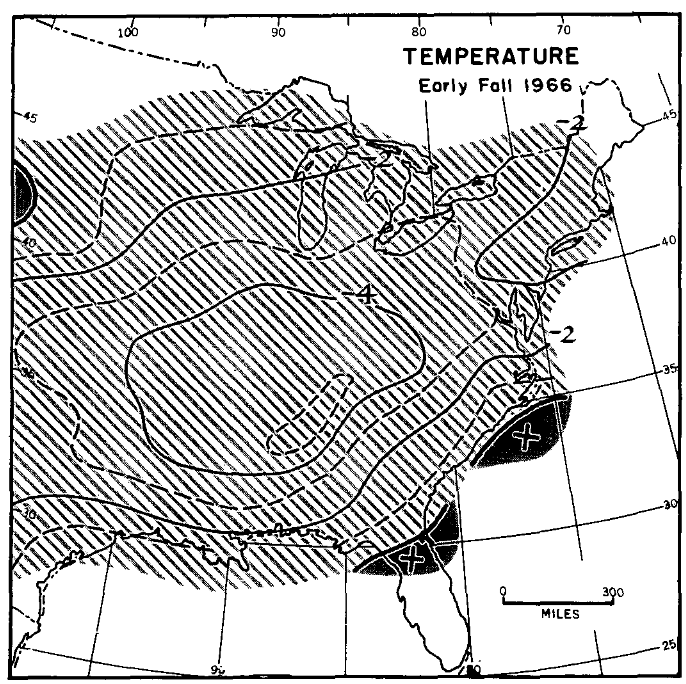

FIGURE 13.—Same as figure 12, for September/October 1966.

pattern of large negative deviations for early fall, but even they did not reach the earlier core extremes. (The mean early fall departures from the 1931–1960 normals for 1937 are given in figure 12.) However, just after this evaluation of the historical records was completed, the author received the December 1966 issue of *Weatherwise* [1]. In it, the "Departures from Normal" for the 2 months of September and October 1966 are published based on ESSA records. A simple graphical averaging of these two maps results in a departure map for fall, 1966, reproduced in figure 13—and a comparison with figure 4 shows an amazing similarity indeed. A succession of such years as 1966 obviously would give rise to a temperature pattern quite close to that of the 1830/1840 period. Whether or not we are reverting to this somewhat colder "normal" state now, cannot be established yet, but this may be a first indication (already suspected by some other authors (e.g. Lamb [12]), that our climate is reverting to the kind of patterns common in the 19th century, i.e. that the recent "warming trend" is over. If this hypothesis is correct, it will have some distinct effects on a number of problem areas. A downward trend of the mean temperature, especially in early fall, will tend to increase the likelihood of early frosts (such as Wisconsin experienced in 1965 with some killing frost in lowlands on July 6) and thus may require changes in agricultural practices. One should not forget that an average decrease in mean monthly averages of about 4° is equivalent to a displacement of the isotherms by about 4° latitude or 250 to 300 mi., or to reaching a certain temperature threshold about 10 days earlier in fall. All in all, these results apparently justify the statement, which often is being made, namely that the climate our forefathers lived under was really somewhat more severe than that which was normal in the first half of this century.

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